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A STUDY OF MASS FLOW MEASUREMENTS USING
ORIFICES IN THE IMPULSE BASE FLOW FACILITY

By

Lorant Pallós [1963] 32 p refs

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A STUDY OF MASS FLOW MEASUREMENTS USING ORIFICES IN THE IMPULSE BASE FLOW FACILITY

By

Lorant Pallós

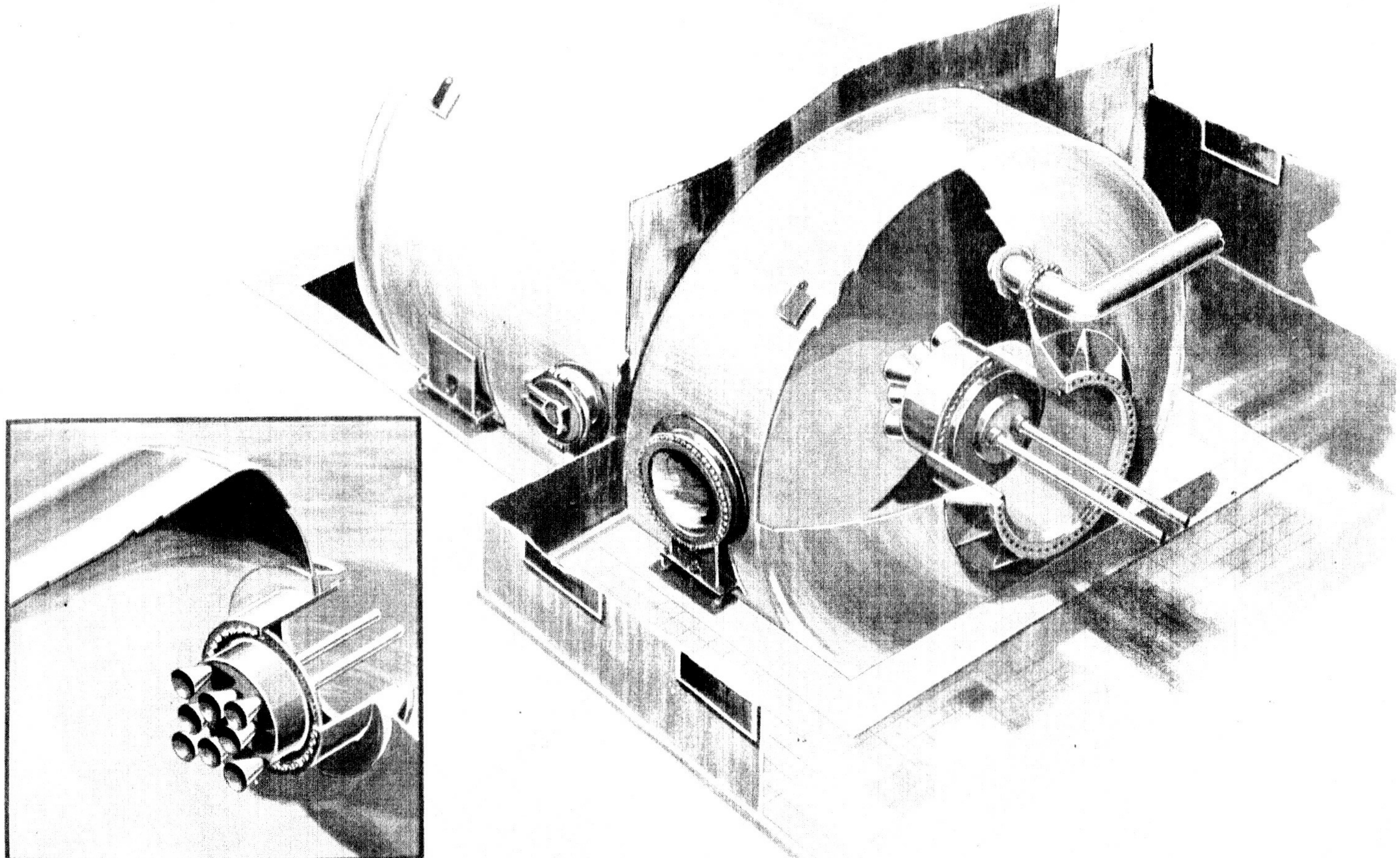
ABSTRACT

23819

A theoretical study of mass flow measurements was conducted for the Impulse Base Flow Facility. The orifice method is to be used for this measurement. This note presents an analysis of this technique, both above and below the critical pressure ratio. Discussed are the equations needed to determine the mass flow as a function of the charge tube pressure, the orifice diameter and flow coefficients including the orifice static pressure and Mach number function. This study presents some representative charts for oxygen which can be used to select the orifice for a specified performance to design a constant pressure combustor.

It is pointed out that an error in reference 4 has been propagated through several other reports. This report presents the correct equations for this analysis.

AUTHOR



ARTIST CONCEPTION OF THE IMPULSE BASE FLOW FACILITY

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MTP-AERO-63-59

August 5, 1963

A STUDY OF MASS FLOW MEASUREMENTS USING ORIFICES IN THE IMPULSE BASE FLOW FACILITY

By

Lorant Pallós

SPECIAL PROJECTS SECTION
EXPERIMENTAL AERODYNAMICS BRANCH
AEROBALLISTICS DIVISION

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

DEFINITION OF SYMBOLS

Symbol	Definition
A_e	Effective orifice area, in^2.
A_o	Orifice area, in^2.
A_t	Charge tube area, in^2.
C_i	Incompressible orifice coefficient.
C_D	Compressible orifice coefficient.
d_e	Effective orifice diameter, in.
d_o	Orifice diameter, in.
d_t	Charge tube diameter, in.
D	Mach number function
D_o	Mach number function in orifice.
D_2	Mach number function upstream from orifice.
f	Force defect coefficient $= \frac{1}{C_i} - \frac{1}{2C_i^2}$.
F	$= 2f = \frac{2C_i - 1}{C_i^2}$.
g	Acceleration of gravity = 32.2 ft/sec^2.
$(K_n)^2$	$= \frac{2n}{n-1} r^{\frac{2}{n}} \left(1 - r^{\frac{n-1}{n}}\right)$ for r and $= n r_c^{\frac{n+1}{n}}$ for r_c.
$n = \gamma$	Specific heat ratio.
M	Mach number.

DEFINITION OF SYMBOLS (Cont'd)

Symbol	Definition
M_o	Mach number in orifice.
M_2	Mach number in charge tube upstream from orifice.
MW	Molecular weight, lb/lb mole.
O/F	Propellant mixture ratio.
P_1	Charge tube pressure, PSIA.
P_2	Static pressure upstream from orifice, PSIA.
$P_2{}^o$	Stagnation pressure upstream from orifice, PSIA.
$P_3 = P_c$	Pressure downstream from orifice, PSIA.
r	Pressure ratio across orifice.
r_c	Critical pressure ratio across the orifice.
Re	Reynolds number $= 2.272 \times 10^4 \frac{W}{d_t}$.
R	Gas constant $= \frac{1545}{MW}$.
T^o	Absolute temperature, °R(460 + t).
W	Weight flow, lb/sec.
μ	Absolute viscosity, centipoise.

I. INTRODUCTION

The short duration techniques for the experimental study of rocket base heating problems have been developed by the Cornell Aeronautical Laboratory. The basic principle is to store the fuel and oxidizer gases in charge tubes separated from a combustion chamber by diaphragms or quick-acting valves (see Figure 1a). Rupture of the diaphragms or opening of the valves permits the gases to flow into the combustion chamber where ignition and burning occur, producing a high enthalpy gas. This high enthalpy gas then flows through the model rocket engine nozzles. Base heating measurements are made during this process which lasts only in the order of milliseconds.

This technique has many advantages over more conventional base heating experimental methods, but some fundamental problems are still to be solved. One of these problems is the accurate measurement of the mass flows so that the desired ratio of fuel to oxidizer may be obtained. The orifice method has been used for this measurement in the short duration facility. This note presents an analysis of this technique. Discussed are the equations needed for this analysis. They include (1) orifice flow coefficients both from compressible and incompressible fluid, (2) the mass flow including the Mach number functions, (3) the orifice static pressure, and (4) the charge tube pressures. This note also presents some representative charts for oxygen which can be used to select the orifice for a specified performance.

II. THE WEIGHT FLOW THROUGH AN ORIFICE

The weight flow through an orifice can be expressed as a function of the gas properties, the orifice stagnation pressure P_2^{o}, the effective orifice area A_e, and the orifice Mach number function D_o (see Fig. 1b).

$$W = \left(\frac{ng}{RT^{o}}\right)^{1/2} P_2^{o} A_e D_o. \tag{2-1}$$

According to the continuity relationship, the following equation can be written

$$A_e D_o = A_t D_2. \tag{2-2}$$

The general weight flow equation can be obtained from equations (2-1) and (2-2).

$$W = A_t \left(\frac{ng}{RT^o}\right)^{1/2} P_2^{\,o} D_2. \tag{2-3}$$

It can be seen that the weight flow is proportional to the Mach number function D_2 upstream from the orifice (see Fig. 1b), which can be determined from equation (2-2),

$$D_2 = \frac{A_e}{A_t} D_o, \tag{2-4}$$

and the effective orifice area A_e can be expressed with the orifice coefficient C_D for compressible flow

$$A_e = C_D A_o. \tag{2-5}$$

From equations (2-4) and (2-5),

$$D_2 = \frac{A_o}{A_t} C_D D_o. \tag{2-6}$$

$$D_2 = \left(\frac{d_o}{d_t}\right)^2 C_D D_o. \tag{2-7}$$

This equation shows that the Mach number function D_2 is a function of the orifice and tube diameter ratio, and is proportional to the orifice coefficient C_D, and the orifice Mach number function D_o.

III. THE INCOMPRESSIBLE ORIFICE COEFFICIENT

The incompressible orifice coefficient C_i varies from .6 to .7 depending on the d_o/d_t ratio (values carried in many handbooks). At given d_o/d_t ratio, the orifice coefficients vary with Reynolds number up to a certain value of Reynolds number, and then become constant (see Figure 2). This critical Reynolds number can be expressed as a function of the weight flow W, the charge tube diameter d_t, and the absolute viscosity μ:

$$(R_e)_{min.} = 2.272 \times 10^4 \frac{(W)_{min.}}{d_t \mu}. \tag{3-1}$$

The values of critical weight flow for oxygen (μ = .0205 at T = 540°R) and ethylene (μ = .0099 at T = 520°R) can be expressed as

$$(O_2)\ W_{min.} = d_t \frac{(R_e)_{min.}}{11.081 \times 10^5}. \tag{3-2}$$

$$(C_2H_4)\ W_{min.} = d_t \frac{(R_e)_{min.}}{22.945 \times 10^5}. \tag{3-3}$$

These values are shown in Figures 3 and 4 for the case d_t = 1 in. and d_t = 1.75 in., respectively.

IV. THE COMPRESSIBLE ORIFICE COEFFICIENT

The effect of compressible flow was analyzed by Jobson (Ref. 4). This theory uses the incompressible orifice coefficient as a reference point in the short duration base heating technique. There is an error in that report (p. 770, equation 15). Other investigators have used this equation with the error. One of the purposes of this report is to make this correction.

A. C_D for Supercritical Flow ($0 < r < r_c$)

Jobson's report yields a quadratic expression for C_D:

$$fC_D^2 - \frac{1}{r_c^{\frac{1}{n}}}\left[1 + \frac{(r_c - r)\, r_c^{\frac{1}{n}}}{(K_n)^2}\right] C_D + \frac{1 - r}{(K_n)^2} = 0. \tag{4-1}$$

From this expression, the correct equation for C_D is

$$C_D = \frac{1}{2fr_c^{\frac{1}{n}}} \left\{ \left[1 + \frac{(r_c - r)\, r_c^{\frac{1}{n}}}{(K_n)^2} \right] - \left[\left(1 + \frac{(r_c - r)\, r_c^{\frac{1}{n}}}{(K_n)^2} \right)^2 \right. \right.$$

$$\left. \left. - \frac{\left(2r_c^{\frac{1}{n}}\right)^2 (1 - r) f}{(K_n)^2} \right]^{1/2} \right\} \qquad (4\text{-}2)$$

where

$$2f = \frac{2C_i - 1}{C_i^2} \qquad (4\text{-}3)$$

$$r_c = \left(\frac{2}{n + 1} \right)^{\frac{n}{n-1}} \qquad (4\text{-}4)$$

$$(K_n)^2 = \frac{2n}{n - 1}\, r_c^{\frac{2}{n}} \left(1 - r_c^{\frac{n-1}{n}} \right). \qquad (4\text{-}5)$$

These equations show that the orifice coefficient is a function of the orifice pressure ratio, r, the incompressible orifice coefficient C_i, and the specific heat ratio n. Equation (4-2) can be simplified by modifying it and substituting r_c and $(K_n)^2$ from equations (4-4) and (4-5).

From equation (4-4),

$$r_c^{\frac{n-1}{n}} = \left(\frac{2}{n + 1} \right), \qquad (4\text{-}6)$$

$$\left(1 - r_c^{\frac{n-1}{n}} \right) = \frac{n - 1}{n + 1}\ . \qquad (4\text{-}7)$$

After substituting equations (4-5) and (4-6) into equation (4-7), we obtain

$$(K_n)^2 = n\left(\frac{2}{n+1}\right) r_c^{\frac{2}{n}} = n r_c^{\frac{n+1}{n}} . \tag{4-8}$$

Two terms can be simplified in equation (4-2) with equation (4-8).

$$B = \left[1 + \frac{(r_c - r)\, r_c^{\frac{1}{n}}}{(K_n)^2}\right] \tag{4-9}$$

$$= 1 + \frac{(r_c - r)}{n r_c}$$

$$= \left(\frac{n+1}{n} - \frac{r}{n r_c}\right) \tag{4-10}$$

and

$$\frac{\left(2r^{\frac{1}{n}}\right)^2}{(K_n)^2} = 2\left(\frac{n+1}{n}\right) . \tag{4-11}$$

The compressible orifice coefficient for supercritical flow can be expressed from equations (4-2), (4-10), and (4-11).

$$\boxed{\begin{aligned} C_D &= \frac{1}{F r_c^{\frac{1}{n}}}\left[B - \sqrt{B^2 - F\left(\frac{n+1}{n}\right)(1 - r)}\,\right] \\ F &= \frac{2C_i - 1}{C_i^2} \; ; \quad B = \left(\frac{n+1}{n} - \frac{r}{n r_c}\right) \end{aligned}} \tag{4-12}$$

B. C_D for Subcritical Flow ($r_c < r < 1$)

The compressible orifice coefficient C_D, according to Jobson's report can also be expressed as a function of the specific heat ratio n, the orifice pressure ratio r, and the incompressible orifice coefficient C_i:

$$C_D = \frac{1}{2fr^{\frac{1}{n}}}\left[1 - \sqrt{1 - \frac{\left(2r^{\frac{1}{n}}\right)^2 (1 - r)f}{(K_n)^2}}\right] \tag{4-13}$$

where

$$2f = \frac{2C_i - 1}{C_i{}^2} \tag{4-14}$$

$$(K_n)^2 = \frac{2n}{n - 1} r^{\frac{2}{n}} \left(1 - r^{\frac{n-1}{n}}\right) . \tag{4-15}$$

Equation (4-13) can be simplified by modifying the $(2r^{\frac{1}{n}})^2/(K_n)^2$ term substituting $(K_n)^2$ from equation (4-15).

$$\frac{\left(2r^{\frac{1}{n}}\right)^2}{(K_n)^2} = \frac{2\left(\frac{n - 1}{n}\right)}{\left(1 - r^{\frac{n-1}{n}}\right)} . \tag{4-16}$$

The compressible orifice coefficient can be obtained from equations (4-13) and (4-16).

$$\boxed{\begin{aligned} C_D &= \frac{1}{Fr^{\frac{1}{n}}}\left[1 - \sqrt{1 - F\left(\frac{n - 1}{n}\right)\frac{(1 - r)}{\left(1 - r^{\frac{n-1}{n}}\right)}}\right] \\ F &= \frac{2C_i - 1}{C_i{}^2} \end{aligned}} . \tag{4-17}$$

The compressible orifice coefficient at any particular pressure ratio may be found by first determining F and substituting this value into either equation (4-12) or (4-17) when r is greater or less than the critical value r_c, respectively. A chart has been obtained in this way (see Figure 5) for the typical case of n = 1.4 where the pressure ratio, r, ranges from 0 to 1, and the orifice tube diameter ratio d_o/d_t ranges from 0 to .86.

V. THE MACH NUMBER FUNCTION D_2

The Mach number function D_2, accroding to equation (2-7) is

$$\boxed{D_2 = \left(\frac{d_o}{d_t}\right)^2 C_D \, D_o} \quad . \tag{5-1}$$

It can be seen that the D_2 is a function of the orifice coefficient C_D and the orifice Mach number function D_o. The orifice coefficient and the orifice Mach number function are different according to the pressure ratio (see equations (4-12) and (4-17)).

D_o can be expressed for supercritical flow as

$$D = M\left(1 + \frac{n-1}{2} M^2\right)^{-\frac{(n+1)}{2(n-1)}} \quad . \tag{5-2}$$

Since M_o = 1 at supercritical flow,

$$D_o = \left(\frac{2}{n+1}\right)^{\frac{(n+1)}{2(n-1)}} \quad . \tag{5-3}$$

Substituting equation (4-6) into equation (5-3), we obtain

$$D_o = r_c^{\frac{n+1}{2n}} \quad . \tag{5-4}$$

Since the orifice Mach number for subcritical flow is a function of the orifice pressure ratio r,

$$r = \left(1 + \frac{n - 1}{2} M^2\right)^{-\frac{n}{(n-1)}} . \qquad (5\text{-}5)$$

The orifice Mach number function D_o for subcritical flow can be obtained from equations (5-2) and (5-5),

$$D_o = \sqrt{\frac{2}{n - 1}\left(r^{\frac{2}{n}} - r^{\frac{n+1}{n}}\right)} . \qquad (5\text{-}6)$$

The Mach number function D_2 can be expressed:

1. For supercritical flow from equations (4-12), (5-1), and (5-4) as

$$\boxed{\begin{gathered} D_2 = \frac{1}{F}\left(\frac{d_o}{d_t}\right)^2 \left(\frac{2}{n + 1}\right)^{1/2} \left[B - \sqrt{B^2 - F\left(\frac{n + 1}{n}\right)(1 - r)}\,\right] \\ B = \left(\frac{n + 1}{n} - \frac{r}{nr_c}\right) \end{gathered}} . \qquad (5\text{-}7)$$

2. For subcritical flow from equations (4-17), (5-1), and (5-6) as

$$\boxed{\begin{gathered} D_2 = \frac{1}{F}\left(\frac{d_o}{d_t}\right)^2 \left[A - \sqrt{A^2 - F\,\frac{2}{n}\,(1 - r)}\,\right] \\ A = \sqrt{\frac{2}{n - 1}\left(1 - r^{\frac{n-1}{n}}\right)} \end{gathered}} . \qquad (5\text{-}8)$$

VI. THE ORIFICE STATIC PRESSURE P_2

The orifice static pressure P_2 can be expressed using stagnation pressure P_2^{o} and the Mach number M_2.

$$\frac{P_2^{o}}{P_2} = \left(1 + \frac{n-1}{2} M_2^2\right)^{\frac{n}{n-1}} . \qquad (6\text{-}1)$$

It can also be obtained from equations (5-2) and (6-1) as a function of the stagnation pressure P_2^{o} and the Mach number function.

$$D_2 = \sqrt{\frac{2}{n-1}\left[\left(\frac{P_2}{P_2^{o}}\right)^{\frac{2}{n}} - \left(\frac{P_2}{P_2^{o}}\right)^{\frac{n+1}{n}}\right]} . \qquad (6\text{-}2)$$

VII. THE CHARGE TUBE PRESSURE P_1

The charge tube pressure can be obtained in three different ways:

1. It is a function of the static pressure P_2 and the Mach number M_2. When the diaphragm of the supply tube is ruptured, an expansion wave propagates into the stationary gas, accelerating it to M_2. The pressure across the expansion wave is

$$\frac{P_1}{P^2} = \left(1 + \frac{n-1}{2} M_2\right)^{\frac{2n}{n-1}} . \qquad (7\text{-}1)$$

2. It can be expressed with the stagnation pressure P_2^{o}. The stagnation to static pressure ratio is

$$\frac{P_2^{o}}{P_2} = \left(1 + \frac{n-1}{2} M_2^2\right)^{\frac{n}{n-1}} . \qquad (7\text{-}2)$$

From equations (7-1) and (7-2),

$$\frac{P_2{}^{o}}{P_1} = \left[\frac{1 + \frac{n-1}{2} M_2{}^2}{\left(1 + \frac{n-1}{2} M_2\right)^2}\right]^{\frac{n}{n-1}} . \qquad (7\text{-}3)$$

3. The charge tube pressure can be obtained also by the Mach number function D_2 from equations (5-2) and (7-1).

$$D_2 = \frac{\frac{2}{n-1} H}{\left(1 + \frac{2}{n-1} H^2\right)^{\frac{n+1}{2(n-1)}}} . \qquad (7\text{-}4)$$

$$H = \left[\left(\frac{P_1}{P_2}\right)^{\frac{n-1}{2n}} - 1\right]. \qquad (7\text{-}5)$$

VIII. SUMMARY OF EQUATIONS

The equations frequently used in design of weight flow measurement with orifices at short duration technique are summarized.

<u>The Weight Flow</u>

$$W = A_t \left(\frac{ng}{RT^{o}}\right)^{1/2} P_2{}^{o} \left(\frac{d_o}{d_t}\right)^2 C_D D_o$$

$$= A_t \left(\frac{ng}{RT^{o}}\right)^{1/2} P_2{}^{o} D_2$$

$$= A_t \left(\frac{ng}{RT^{o}}\right)^{1/2} \frac{P_3}{r} D_2 .$$

The Orifice Coefficient

1. For Supercritical Flow ($0 < r < r_c$):

$$C_D = \frac{1}{F r_c^{\frac{1}{n}}} \left[B - \sqrt{B^2 - F\left(\frac{n+1}{n}\right)(1-r)} \right]$$

$$B = \frac{n+1}{n} - \frac{r}{n r_c}$$

$$F = \frac{2C_i - 1}{C_i^2}$$

$$r_c = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}} .$$

2. For Subcritical Flow ($r_c < r < 1$):

$$C_D = \frac{1}{F r^{\frac{1}{n}}} \left[1 - \sqrt{1 - F\left(\frac{n-1}{n}\right) \frac{(1-r)}{\left(1 - r^{\frac{n-1}{n}}\right)}} \right].$$

The Mach Number Function D_2

1. For Supercritical Flow ($0 < r < r_c$):

$$D_2 = \frac{1}{F}\left(\frac{d_o}{d_t}\right)^2 \left(\frac{2}{n+1}\right)^{1/2} \left[B - \sqrt{B^2 - F\left(\frac{n+1}{n}\right)(1-r)} \right]$$

$$B = \frac{n+1}{n} - \frac{r}{n r_c} .$$

2. For Subcritical Flow ($r_c < r < 1$):

$$D_2 = \frac{1}{F}\left(\frac{d_o}{d_t}\right)^2 \left[A - \sqrt{A^2 - F\,\frac{2}{n}\,(1 - r)}\right]$$

$$A = \sqrt{\frac{2}{n-1}\left(1 - r^{\frac{n-1}{n}}\right)} \;.$$

The Orifice Static Pressure P_2

$P_2 = f(P_2^{\circ}, M_2, n)$

$$\frac{P_2^{\circ}}{P_2} = \left(1 + \frac{n-1}{2}\,M_2^2\right)^{\frac{n}{n-1}} \;.$$

$P_2 = f(P_2^{\circ}, D_2, n)$

$$D_2 = \sqrt{\frac{2}{n-1}\left[\left(\frac{P_2}{P_2^{\circ}}\right)^{\frac{2}{n}} - \left(\frac{P_2}{P_2^{\circ}}\right)^{\frac{n+1}{n}}\right]} \;.$$

The Change Tube Pressure P_1

$P_1 = f(P_2, M_2, n)$

$$\frac{P_1}{P_2} = \left(1 + \frac{n-1}{2}\,M_2\right)^{\frac{2n}{n-1}} \;.$$

$P_1 = f(P_2^{\circ}, M_2, n)$

$$\frac{P_1}{P_2^{\circ}} = \left[\frac{1 + \frac{n-1}{2}\,M_2^2}{\left(1 + \frac{n-1}{2}\,M_2\right)^2}\right]^{-\left(\frac{n}{n-1}\right)} \;.$$

$P_1 = f(P_2, D_2, n)$

$$D_2 = \frac{\frac{2}{n-1}\,H}{\left(1 + \frac{2}{n-1}\,H^2\right)^{\frac{n+1}{2(n-1)}}} \;.$$

$$H = \left[\left(\frac{P_1}{P_2}\right)^{\frac{n-1}{2n}} - 1\right] .$$

IX. CONCLUSION

The enthalpy and the combustion temperatures are proportional to the O/F ratio. To obtain the desired temperature, it is necessary to have an accurate mass flow measurement. The charge tube orifice diameters have to be chosen so that the mass outflow through these orifices has to be exactly equal to the mass outflow through the nozzles of the model while maintaining the proper oxidant-fuel mixture ratio.

This report presents the equations and charts needed to select the orifices for the required mass flow at any particular pressure ratio. The charts are presented for oxygen when it is assumed to be a perfect gas and has the specific heat ratio of 1.4 (see Figures 6, 7, 8, and 9). However, the general methods are applicable and the equations are usable for any fuel-oxidizer system.

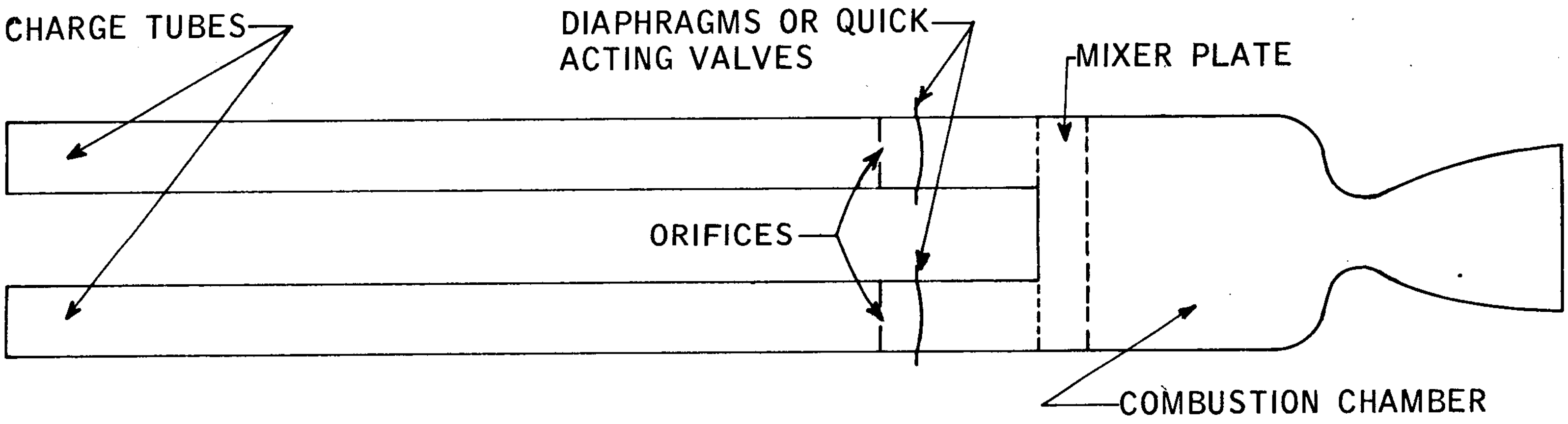


FIGURE 1a. SCHEMATIC ILLUSTRATION OF CONSTANT PRESSURE COMBUSTOR

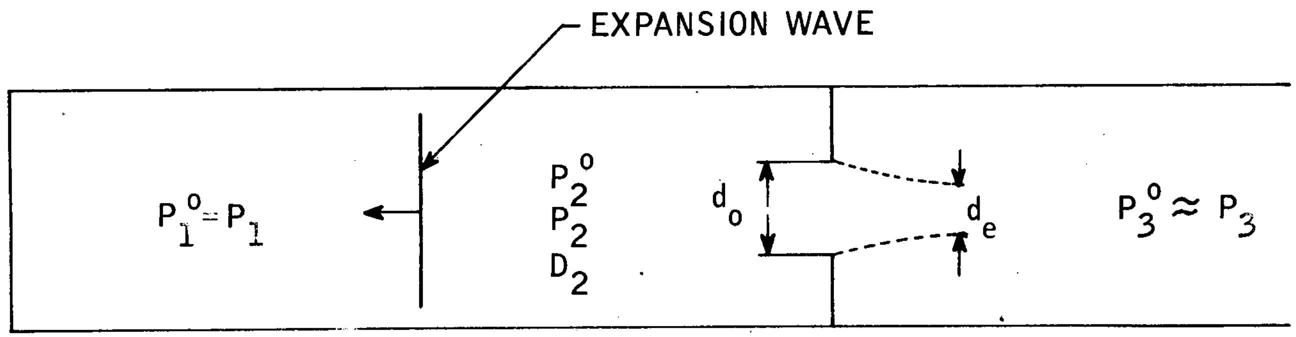


FIGURE 1b. SCHEMATIC ILLUSTRATION OF CHARGE TUBE AND ORIFICE

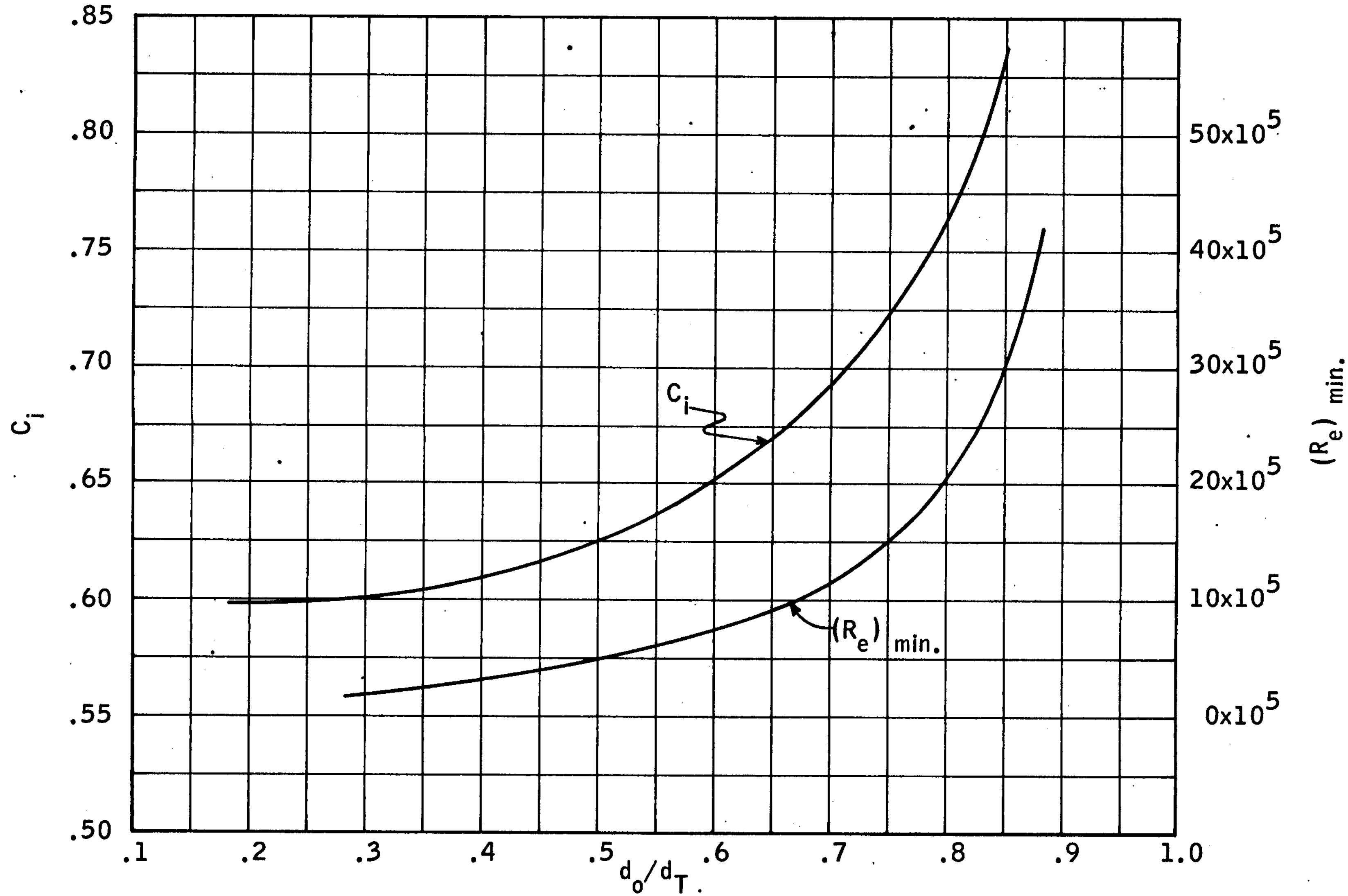


FIGURE 2. INCOMPRESSIBLE ORIFICE COEFFICIENT AND MINIMUM REYNOLDS NUMBER VERSUS ORIFICE TO TUBE DIAMETER RATIO

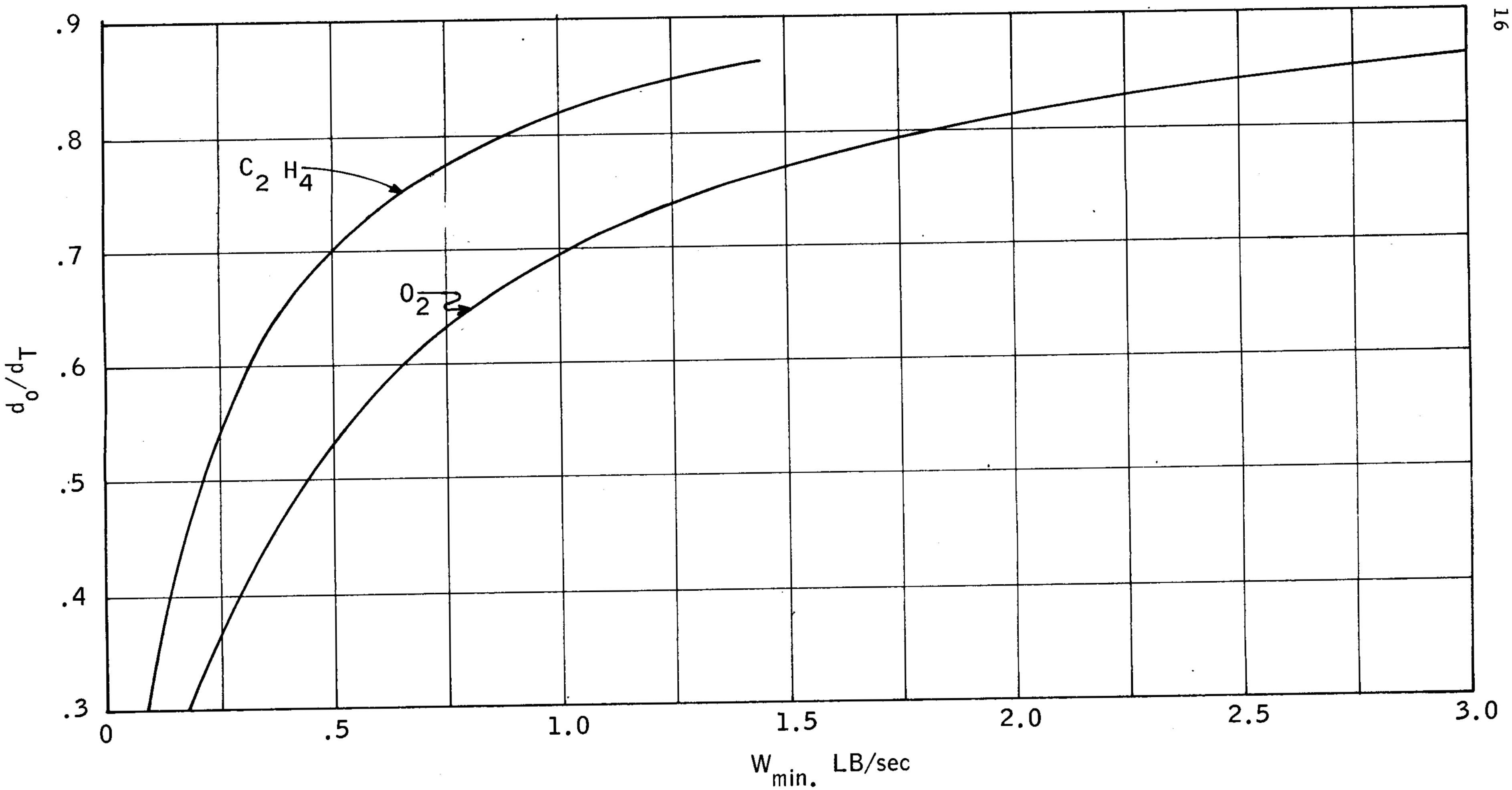


FIGURE 3. ORIFICE TO TUBE DIAMETER RATIO VERSUS CRITICAL WEIGHT FLOW FOR OXYGEN AND ETHYLENE AT $d_T = 1$ in.

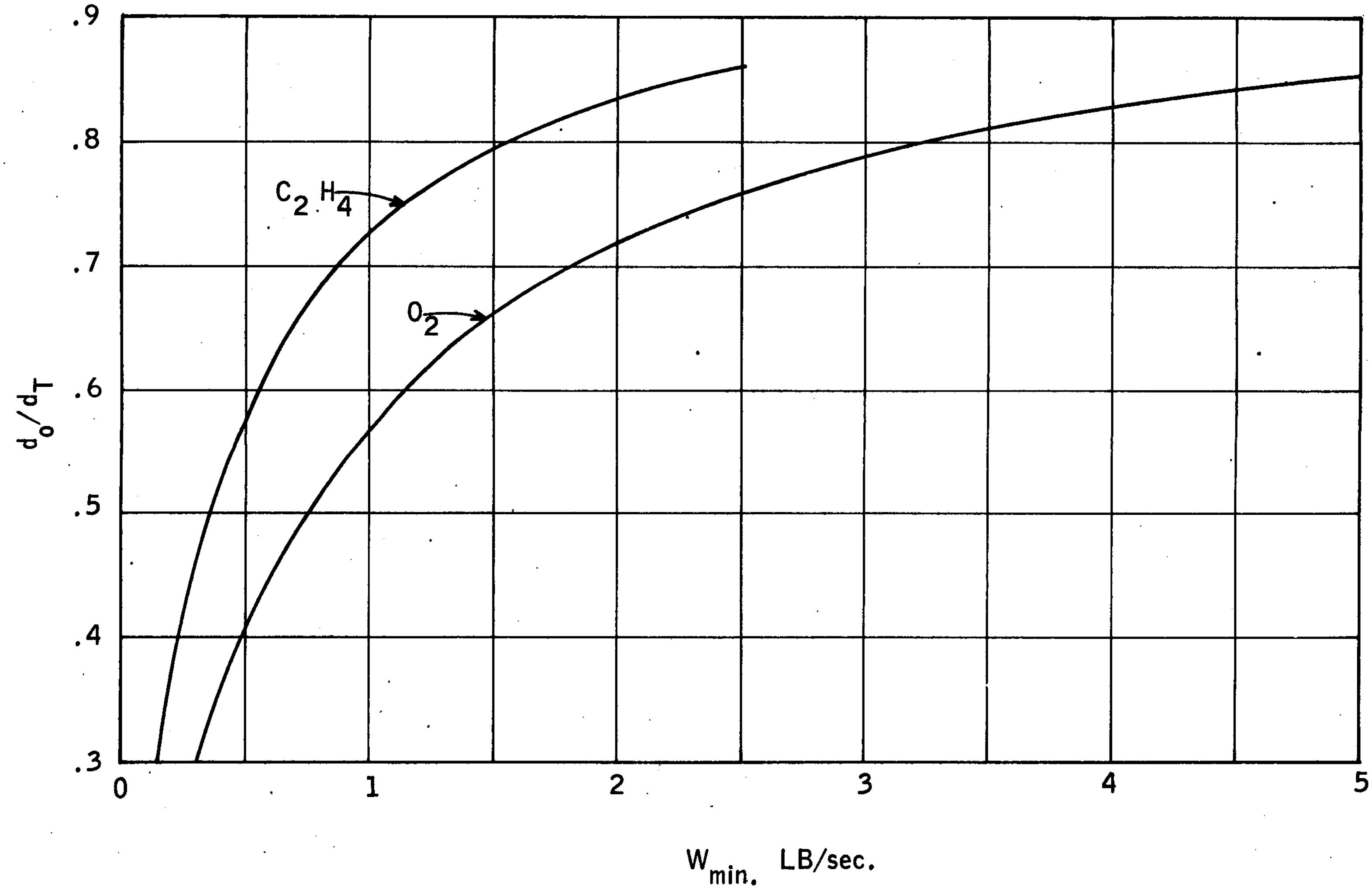


FIGURE 4. ORIFICE TO TUBE DIAMETER RATIO VERSUS CRITICAL WEIGHT FLOW FOR OXYGEN AND ETHYLENE AT d_T = 1.75 in.

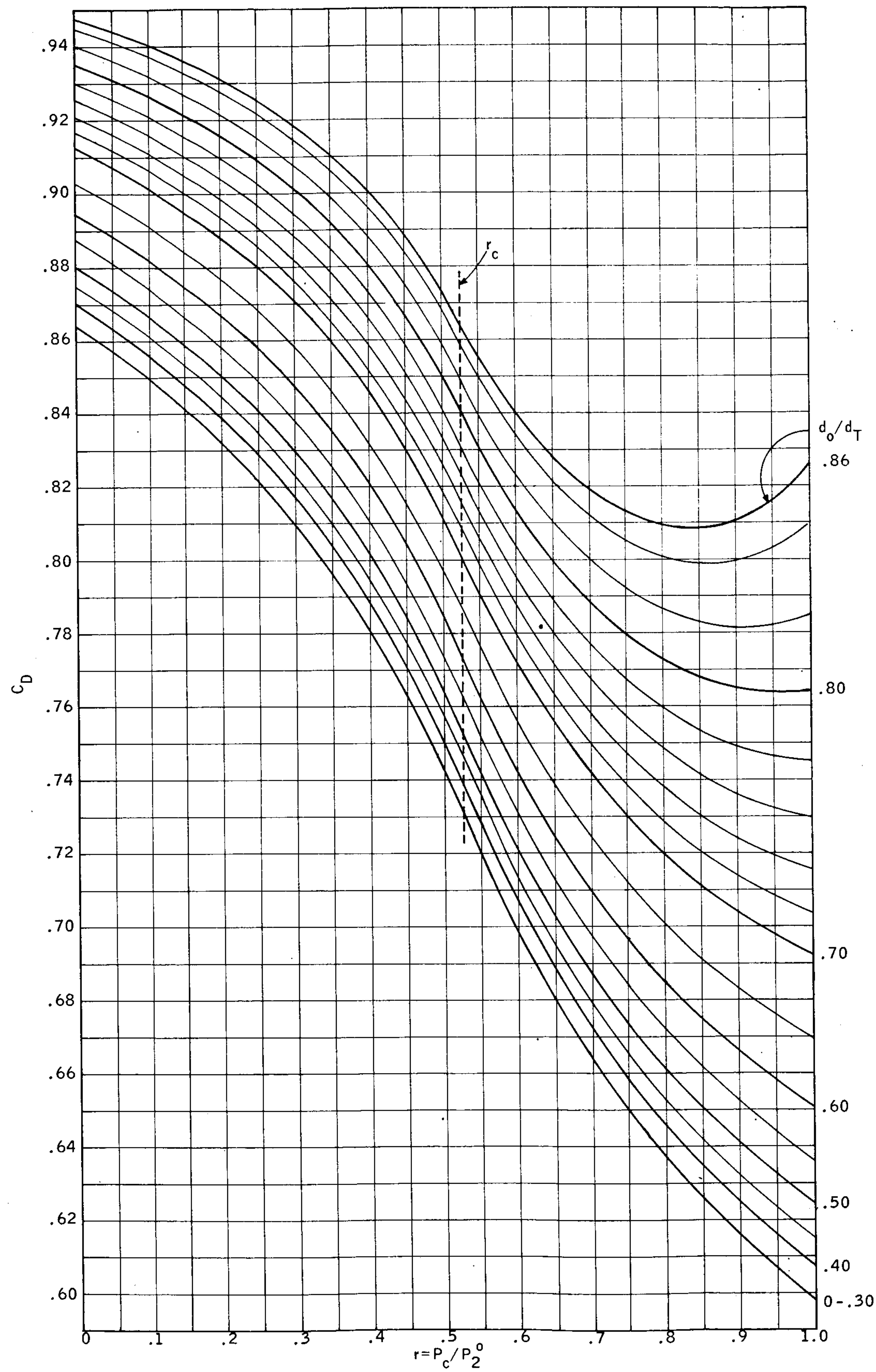


FIGURE 5. COMPRESSIBLE ORIFICE COEFFICIENT C_D FOR OXYGEN AS A FUNCTION OF THE PRESSURE RATIO r FOR VARIOUS VALUES OF THE ORIFICE AND TUBE DIAMETER RATIO d_0/d_T AT n = 1.4

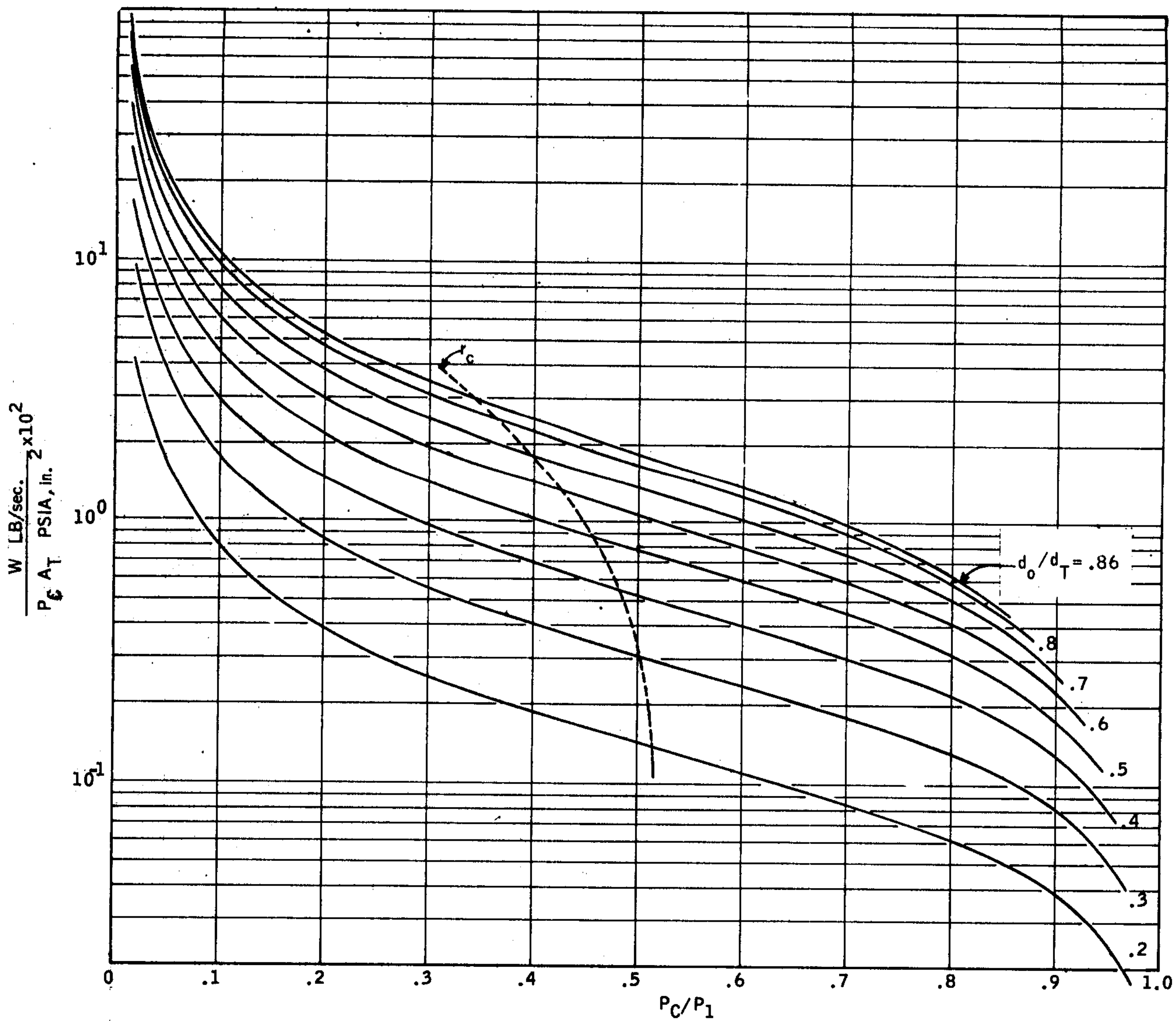


FIGURE 6. OXYGEN WEIGHT FLOW TO COMBUSTION PRESSURE AND TUBE AREA RATIO VERSUS COMBUSTION AND CHARGE TUBE PRESSURE RATIO AT $n = 1.4$ AND VARIOUS VALUES OF d_o/d_T RATIO

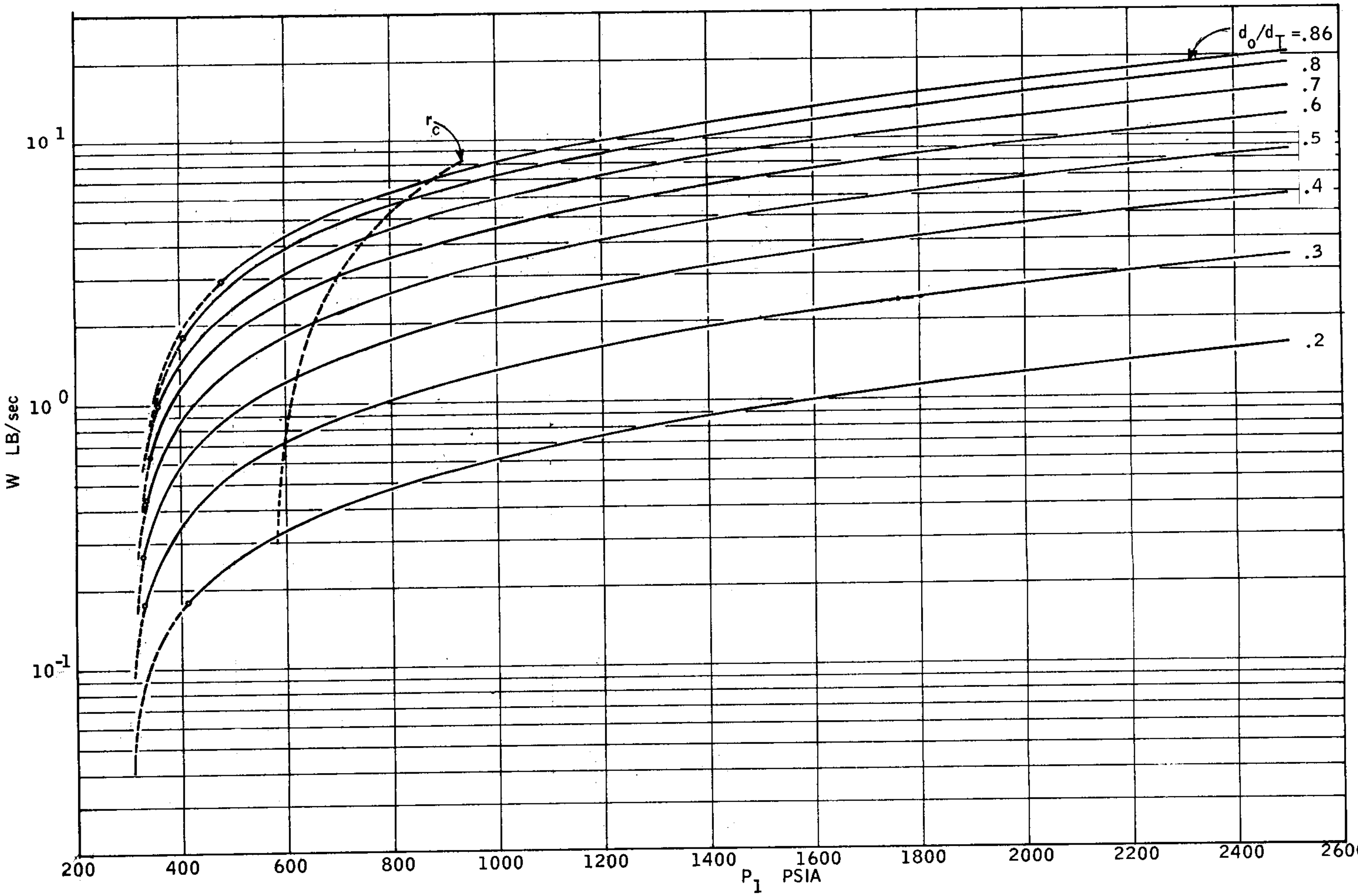


FIGURE 7. OXYGEN WEIGHT FLOW VERSUS CHARGE TUBE PRESSURE AT CONSTANT d_o/d_T RATIOS FOR $n = 1.4$, $d_T = 1$in. AND $P_c = 300$ PSIA

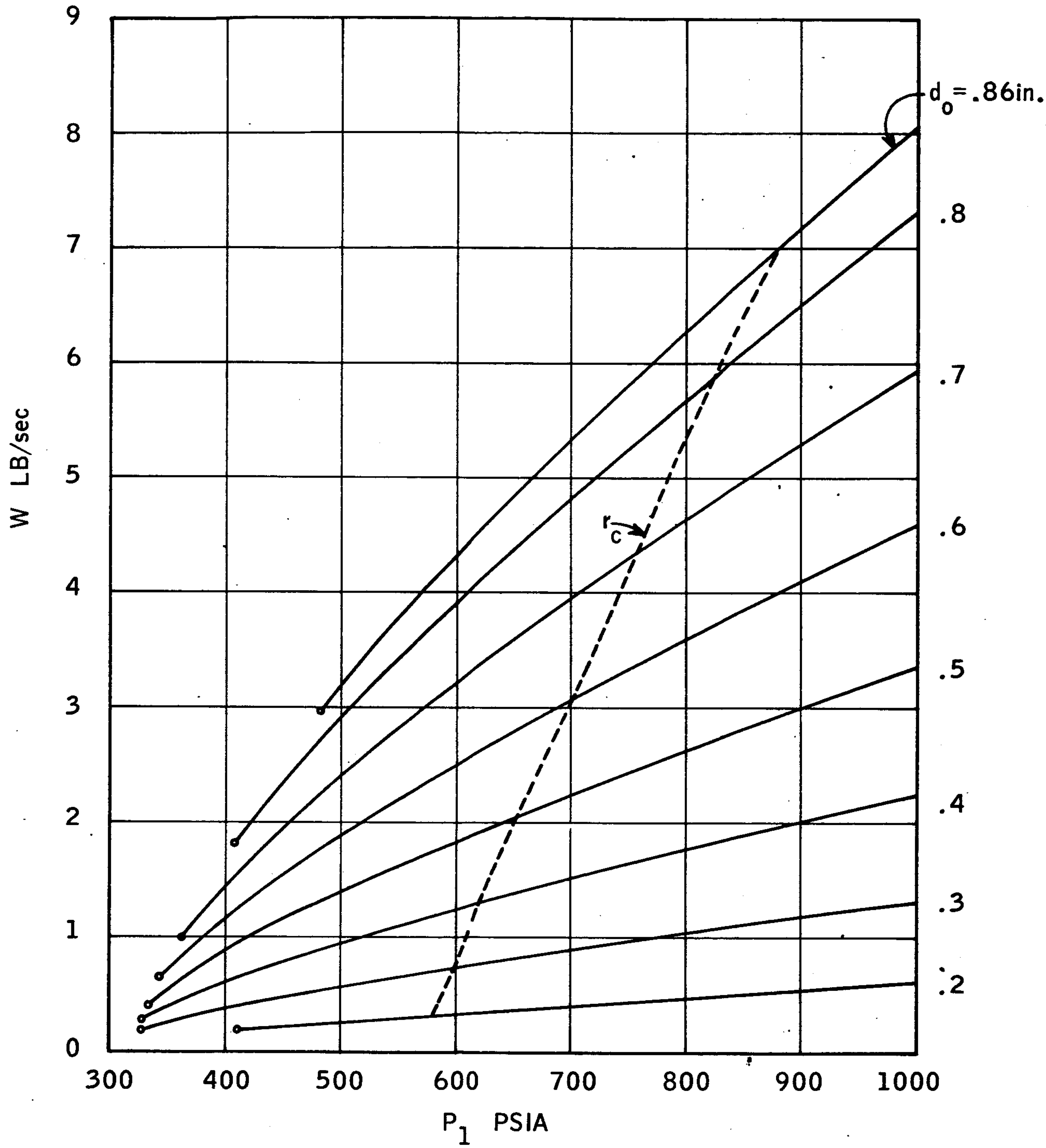


FIGURE 8. OXYGEN WEIGHT FLOW VERSUS TUBE PRESSURE AT CONSTANT ORIFICE DIAMETER FOR $n = 1.4$, $d_T = 1$in. AND $P_C = 300$ PSIA

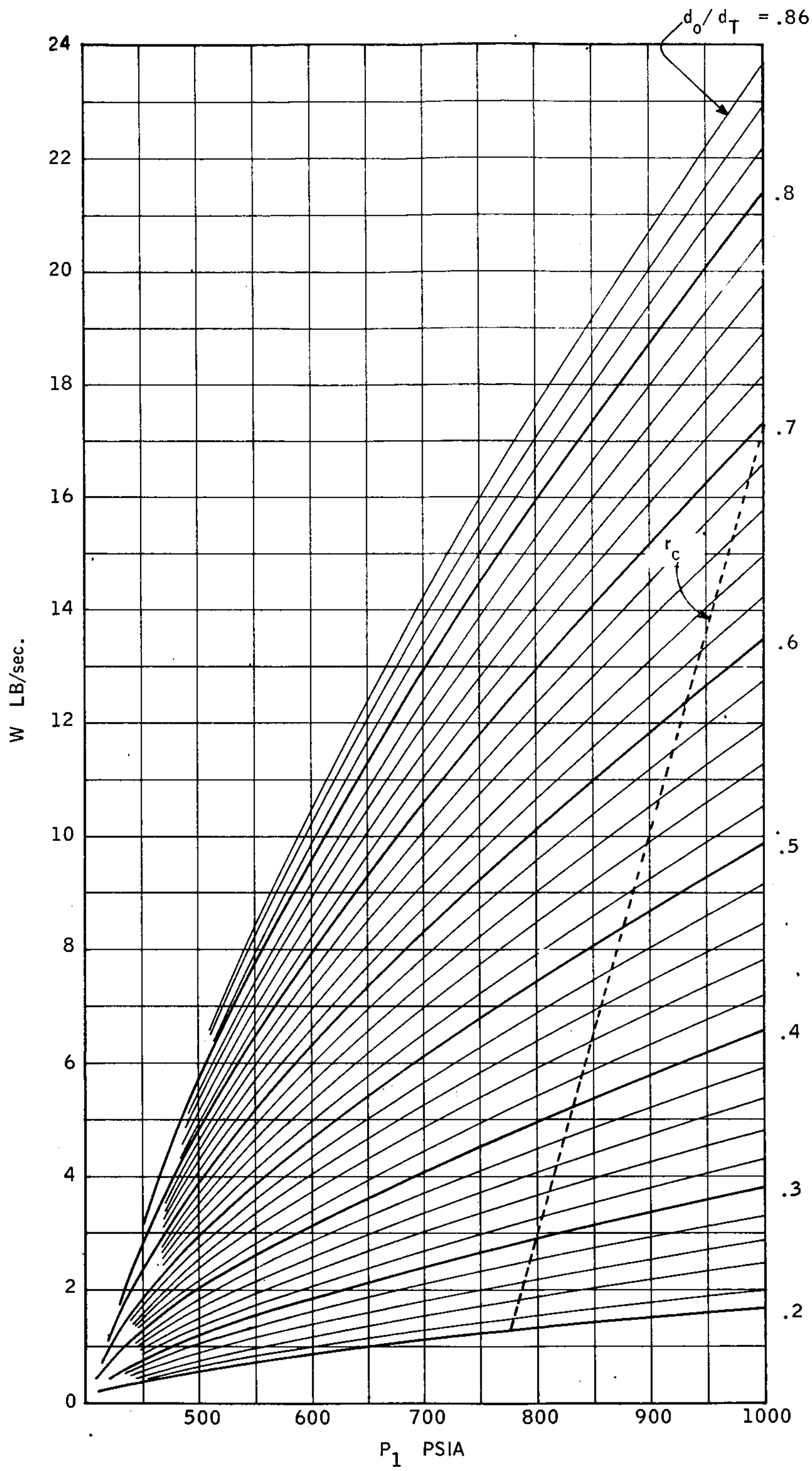


FIGURE 9. OXYGEN WEIGHT FLOW VERSUS CHARGE TUBE PRESSURE AT CONSTANT d_o/d_T RATIOS FOR $n = 1.4$, $d_T = 1.75$ in. AND P_C = 400 PSIA

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A STUDY OF MASS FLOW MEASUREMENTS USING ORIFICES IN THE IMPULSE BASE FLOW FACILITY

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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